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# AN EXPERIMENTAL ANALYSIS OF A HORIZONTAL EARTH TO AIR HEAT EXCHANGER (ETAHE) SYSTEM FOR HOT CLIMATIC CONDITION OF BANGLADESH

**Mohammad Jia Uddin Chowdhury[1,*], Bodius Salam[2] and Md. Akefur Rahman[3]**

[1-3]Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Bangladesh
[1,*]jia.cuet.me10@gmail.com; [2]bsalam@cuet.ac.bd; [3]raeq@rocketmail.com

***Abstract****-Earth-to-air heat exchanger (ETAHE) is a simple system, which draws ventilated supply of air through buried ducts or tubes. This paper deals with the measurement of cooling capacity of an ETAHE in Bangladesh. Fresh air is forced by the blower through pipes which are buried under ground for conditioning and distributing the air in the building. In this way, the fresh air is pre-cooled in summer and pre-heated during the winter. A 36mm inner diameter, 3mm thick and 7.7mlong GI pipe of horizontal arrangement was installed 1.2 m below the earth surface. The inlet and outlet temperatures of air for earth tubes above the ground and underground for different flow rates were measured and finally cooling capacity was quantified.*

**Keywords:** ETAHE, ventilation, cooling capacity

## 1. INTRODUCTION

Saving energy is one of the most important global challenges in our days. Energy crisis is rapidly growing day by day. As a lower middle-income country, energy crisis is the most alarming problem in Bangladesh. Because of the energy crisis, interests have been stimulated in the diversification of energy sources and renewable energy. Meanwhile, environmental concerns push this trend much further. In order to reduce the emissions of greenhouse gases, which are considered the culprit of global warming and sources of pollution, several protocols should be taken for reduction of $CO_2$ emissions. Therefore, the world is now focusing on renewable energy. The more efficient use of renewable energy not only reduces the production of $CO_2$, but also lowers the consumption of primary resources. The earth can be used as a constituent of the energy system. The tempering of earth can be obtained through three primary methods: direct, indirect and isolated. In the direct system, the building envelope is in contact with the earth and conduction through the building elements regulates the interior temperature. Indirect systems (sometimes called ground tubes, ETAHE or ground-coupled air heat exchangers) are promising technology where the tubes placed under the ground, through which air is drawn inside the building. The isolated system uses earth temperatures to increase the efficiency of a heat pump by moderating temperatures at the condensing coil.

The air temperature variations at the ground surface exposed to ambient climate are damped deeper in the ground because of the high thermal inertia of the soil. Therefore, a time lag is introduced between the temperature variations in the ground and at the surface. Hence, at ample depth the ground temperature is lower than the ambient air temperature in summer and higher in winter. A major reduction in electricity consumption of a building is introduced when earth-to-air heat exchanger (ETAHE) system is properly implemented, which helps to avoid air-conditioning units in buildings during hot climatic condition.

Many scientists and researchers analyzed this earth-to-air heat exchanger technique for the last few decades. In addition, building designers exercised this technique for cooling purpose in various hot and arid countries. They found positive and significant results, which influenced others to implement this technique in all kinds of residential and commercial buildings. In about 3000 BC, Iranian architects used underground air tunnels and wind towers for passive cooling [1]. There has been considerable increase in its application as the early exploration of its use in cooling commercial livestock buildings [2]. In North America and Europe, the technique was implemented to cool and heat greenhouses [3]. Mathematical models of ETAHE have also been developed [4, 5]. In India, an analytical model was developed to study about effectiveness of an ETAHE coupled greenhouse located in New Delhi [6]. An ETAHE was also installed to cool part of a guesthouse in India [7].An ETAHE system was as an energy saving technology for a typical hot and humid location in Ningbo, China [8]. In Kuwait, Al-Ajmi et al.[9] studied the earth-to-air heat exchangers for domestic buildings in a desert climate. The outlet air temperature and cooling capacity of ETAHE were predicted in that study. However, information on earth cooling technology in Bangladesh is scarce. This paper deals with the experimental analysis of a horizontal earth to air heat exchanger system (indirect method) for hot climatic condition of Bangladesh.

## 2. EXPERIMENTAL PROCEDURE

Experimental setup consisted of earth tube, blower, voltage regulator, thermometers and orifice meter. The installation of the ETAHE was done at the Mechanical Engineering department building premises, Chittagong University of Engineering and Technology (Latitude 22º27′53.81″N, Longitude 91º58′16.85″E), Chittagong, Bangladesh. Figure 1 shows a schematic diagram of the system. The system utilized a galvanized iron pipe in combination with a blower, motor and a controller. The blower with radial blades of 40 W capacity was direct driven. A regulator controlled the speed of the blower.

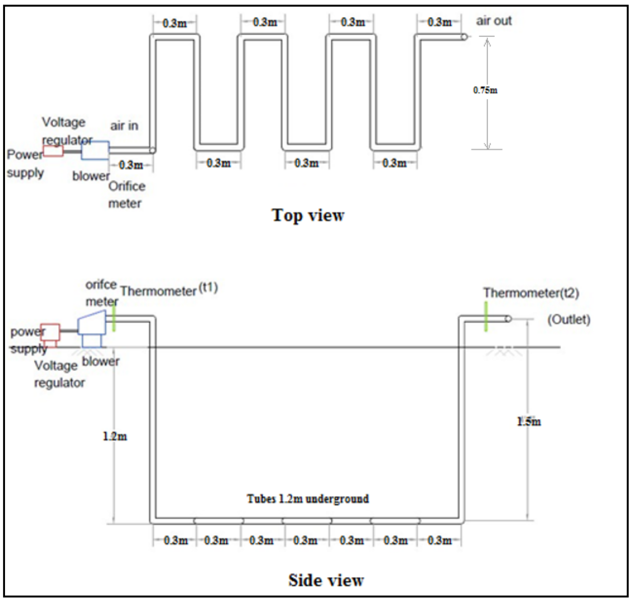

Fig.1: Schematic diagram of experimental system

As the warm air passed through the underground air pipe it cooled off, while the soil around the pipe got heated. This also caused moisture from the soil to move away from the pipe, which decreased the thermal conductivity of the soil [10].

A horizontal, series piping arrangement was used in this system. The horizontal arrangement of 7.68 m GI pipe was made from 36mm inner diameter, 3mm thick GI pipe sections, which were buried 1.2m below the earth surface. The system was connected to above ground by two 1.37m long GI pipes of same diameter. A trench (1.2 m deep, 2.13 m long and 0.91 m wide)was made in department building premises. Figure 2 shows the prototype of the ETAHE system.

For the calculation of cooling capacity data of air inlet temperature, air outlet temperature and airflow rate were taken. Two thermometers measured the temperatures of air entering and leaving the ETAHE. Air was forced to flow into the tube through blower where inlet air temperature reading was taken. During passing through ETAHE air released heat. Air outlet temperature was taken at near the exit of the pipe above the ground.

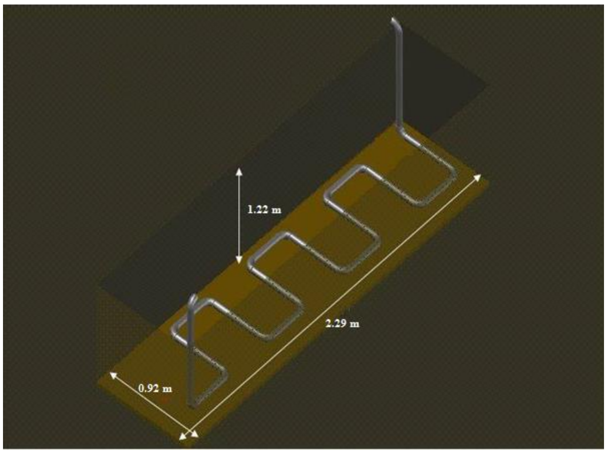

Fig.2: Prototype of the ETAHE system

Two sets of data were taken, one for pipe above the ground and the other for the pipe in underground for evaluating performance of the EATHE system. The volume flow rate of air was measured by an orifice meter connected with U tube manometer. The orifice diameter was 17.78 mm.

## 3. ANALYTICAL ANALYSIS

The volume flow rate of air was determined by orifice flow meter using,

$$\dot{Q} = c_d \sqrt{2gh_a} \left( A_2 \Big/ \sqrt{1 - \left(\frac{A_2}{A_1}\right)^2} \right) \tag{1}$$

The air velocity in the pipe was determined from continuity equation considering incompressible flow,

$$v = \dot{Q} / A_1 \tag{2}$$

Further, the cooling capacity can be determined by,

$$Q = \dot{m} c_p \Delta T \tag{3}$$

Where the mass flow rate of air was determined by,

$$\dot{m} = \dot{Q} \rho \tag{4}$$

Coefficient of performance (COP)is one of the measures of heat exchanger efficiency and is determined by,

$$COP = Q / W_{in} \tag{5}$$

Reynolds number can be expressed as,

$$Re = \rho v d_h / \mu \tag{6}$$

## 4. EXPERIMENTAL DATA AND PERFORMANCE ANALYSIS

When the ETAHE was on the ground, data were taken for both inlet and outlet air temperature for different flow rates or velocities. Figure 3 shows the effect of Reynolds number on air temperatures. It was observed that with the increase of velocity, inlet air temperatures were increased as well as Reynolds number. However, the outlet temperatures were found to be nearly constant. Thereby air temperature differences were found to be increased with the increase of flow rates or velocities. During taking data, the ambient air temperature was 27ºC.

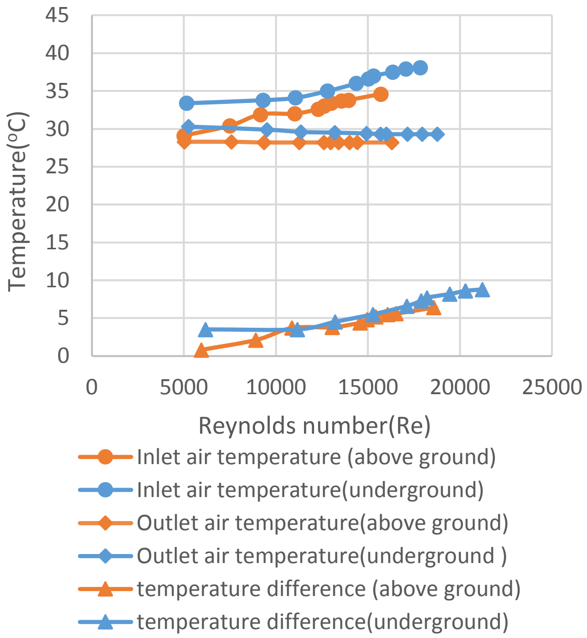

Fig.3: Effect of Reynolds number on temperature

The second set of data was taken after the ETAHE was buried under the ground. During taking data, the ambient air temperature was 31.1ºC. In the graph (Fig. 3), the same trend of Reynolds number effect on temperature as this was for the tubes above ground was observed. However, the temperature differences were found to be higher when the tubes were placed underground.

The cooling capacity and coefficient of performance was calculated by using Eq. (3) and Eq. (5) respectively where several data were taken from Table 1. Air properties were considered in this work to be constant as ρ 1.165 $m^3$/kg and $c_p$ 1006 J/kg.K and $c_d$ was considered as 0.6.

It was observed that (From Table 1) even though temperature difference increased at higher flow rates for underground tubes, but the outlet temperature ($t_2$) was not dropped further when volume flow rate of air reached0.0069$m^3$/s. This was because blower tended to heat up and supply hotter air as flow rate was increased.

Table 1: Cooling capacity and COP of ETAHE(underground)

| Air inlet Temp $t_1$(ºC) | Air outlet Temp $t_2$(ºC) | Volume flow rate $\dot{Q}$ ($m^3$/s) | Mass flow rate $\dot{m}$ (kg/s) | Cooling Capacity Q(Watt) | COP |
|---|---|---|---|---|---|
| 33.8 | 30.3 | 0.0023 | 0.0027 | 9.60 | 0.24 |
| 33.4 | 29.9 | 0.0042 | 0.0049 | 17.37 | 0.43 |
| 34.1 | 29.6 | 0.0050 | 0.0058 | 26.58 | 0.66 |
| 35.0 | 29.5 | 0.0058 | 0.0068 | 37.79 | 0.94 |
| 36.0 | 29.4 | 0.0066 | 0.0077 | 51.21 | 1.28 |
| 36.6 | 29.3 | 0.0069 | 0.0081 | 59.47 | 1.49 |
| 37.0 | 29.3 | 0.0070 | 0.0082 | 64.01 | 1.60 |
| 37.5 | 29.3 | 0.0076 | 0.0088 | 73.05 | 1.83 |
| 37.9 | 29.3 | 0.0079 | 0.0092 | 80.16 | 2.00 |
| 38.1 | 29.3 | 0.0083 | 0.0096 | 85.82 | 2.15 |

## 5. SUMMARY

When ETAHE was on surface it exchanged heat with the surrounding air through the tube surface, the hotter blower air lost heat through the tubes to the surrounding air. Both inlet and outlet temperature was higher than ambient room temperature. When the ETAHE was at underground, the outlet temperature was dropped below ambient temperature as the inlet air released heat to the soil through the pipe surface. Comparison of the earth tube at surface and underground concluded that temperature difference at underground was higher compared to while on above the ground. Figure 1depicts that at higher velocity of air, ETAHE that was underground cooled more effectively compared to while on the surface.

Cooling capacity and COP increased with the increase of mass flow rate as it illustrated in Table 1. Highest value for cooling capacity was 85.82 watt at an air mass flow rate of 0.0096kg/s. The highest value of coefficient of performance (COP) was found to be2.15 (Table 1).

However, main limitation of this study is that it needs available land to accommodate the length of the tubes.

## 6. RECOMMENDATION

The observations in the paper will make it possible to implement an effective ETAHE system and also further analysis to obtain more data and enhancement the heat transfer within the tubes. For more enhanced output, the followings are recommended:

1.Length of the earth tube system should be increased.

2. Increased diameter of tube will result in more contact surface for heat transfer.

3.Earth tubes should be placed even deeper to exploit lower soil temperatures.

4.Paths for air travel above ground should be shorter and well insulated to reduce heat gain.

Hopefully, this paper will help in the pathway of opening new opportunities for efficient use of clean energy, which will lead to a greener pollution free environment in Bangladesh.

## 7. FUTURE WORK

As a future work, we will focus on increasing the coefficient of performance of the ETAHE system.

## 8. REFERENCES

[1] M.N.Bahadori,“Passive cooling systems in Iranian architecture”,*Scientific American*,vol. 238, no. 2, pp.144, 1978.

[2] N.R.Scott, R.A. Parsons andT.A. Kochler, “Analysis and performance ofan earth-air heat exchanger”,*ASAE*, pp. 65-840, 1965.

[3] M.Santamouris, G.Mihalakakou, A.Argiriou andD.N. Asimakopoulos,“On the performance of buildings coupled with earth to air heat exchangers”, *Solar Energy*, vol. 54, no. 6, pp. 375–380, 1995.

[4] V.M.Puri,“Heat and mass transfer analysis and modeling in unsaturated ground soils for buried tube systems”,*Energy in Agriculture*, vol. 6, pp. 179–183,1987.

[5] D.Y. Goswami andA.S.Dhaliwal,“Heat transfer analysis in environmental control using an underground air tunnel”, *Journal of Solar Energy Engineering*, vol. 107, pp. 141-145, 1985.

[6] M.K. Ghosal andG.N.Tiwari,“Modeling and parametric studies for thermal performance of an earth to air heat exchanger integrated with a greenhouse”,*Energy Conversion and Management*,vol. 47, no. 13–14, pp. 1779-1798,2006.

[7] R.L. Sawhney, D. Buddhiand N.M. Thanu,“An experimental study of summer performance of a recirculation type underground air pipe air conditioning system”,*Building and Environment*, vol. 34, pp. 189-196,1999.

[8] J.Darkwa, G.Kokogiannakis,C.L.Magadzire and K.Yuan,“Theoretical and practical evaluation of an earth-tube (E-tube) ventilation system”,*Energy and Buildings*, vol. 43, pp. 728-736,2011.

[9] F. Al-Ajmia, D.L.Loveday and V.I.Hanby, “The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate”,*Building and Environment*, vol. 41, pp. 235-244,2006.

[10] D.Y.Goswami andS.Ileslamlou, “Performance analysis of a closed loop climate control system using underground air tunnel”,*Journal of Solar Energy Engineering*, vol. 112, pp. 76-81, 1990.

## 9. NOMENCLATURE

| **Symbol** | **Meaning** | **Unit** |
|---|---|---|
| $\dot{Q}$ | Volume Flow rate | (m$^3$/s) |
| $C_d$ | Discharge Coefficient | (dimensionless) |
| $A_1$ | Cross sectional area of pipe | (m$^2$) |
| $A_2$ | Constricted area at orifice | (m$^2$) |
| $\rho$ | Air density | (kg/m$^3$ ) |
| $d_h$ | Hydraulic diameter | (m) |
| $\mu$ | Dynamic viscosity | (Ns/m$^2$) |
| $D_1$ | Inner diameter of the pipe | (m) |
| $D_2$ | Diameter of the orifice | (m) |
| v | Velocity of the flow | (ms$^{-1}$) |
| Q | cooling capacity | (W) |
| $\dot{m}$ | mass flow rate | (kg/s) |
| $C_p$ | Specific heat | (J/kg-K) |
| $\Delta T$ | Change of temperature | ($K$) |
| $W_{in}$ | Rate of energy input into the heat exchanger (energy used by blower) | (W) |
| $t_1$ | Air inlet temperature | ($^o$C) |
| $t_2$ | Air exit temperature | ($^o$C) |